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FREQUENCY AND DURATION OF FLOW REVERSAL IN THE LOWER COLUMBIA RIVER, APRIL 1968-MARCH 1970

The hydraulic head generated by some heights of tide can result in changes in direction of current in the lower Columbia River when volume discharges fall below a critical value. In connection with this phenomenon, Clark and Snyder (1969) conducted a study to determine the timing and extent of reversal of flow during an extreme condition of low discharge of water from the river. They determined that flow reversals could increase the accumulation of discharged effluents per given volume of river water by as much as 3.5 times over the accumulation at mean flow rates. Their report showed the need for a continuing record of direction of current in the lower Columbia River to determine the importance of flow reversal at different discharge rates. To help satisfy this need, a floating laboratory (Snyder, Blahm, and McConnell, 1971) was established on the lower Columbia River at river kilometer 117.5 (river mile 73) near Prescott, Oreg., where speed and direction of current were recorded. This report describes the flow-reversal phenomenon at river kilometer 117.5 from data collected between April 1968 and March 1970.

Procedure

The velocity of the river current was measured with a Savonius meter[1] suspended from the laboratory to determine the frequency and duration of flow reversal in the lower Columbia River. With the exception of 21 days, the flow was monitored continuously for a 2-year period. Flow data obtained at Prescott were related to the daily discharge of the river and to the time and height of ocean tides near the river's mouth at Astoria, Oreg.

Daily average flow for the period 1 April 1968 to 30 June 1969, was "gauged flow" furnished by the U.S. Geological Survey office in Portland, Oreg.; daily average flow for the period 1 July 1969 to 31 March 1970, was from information furnished by U.S. Geological Survey offices in Portland, Oreg., and Tacoma, Wash. Time and height of oceanic tides were for Astoria, Oreg.; these data were obtained from tide charts of the NOAA (National Oceanic and Atmospheric Administration) National Ocean Survey.

Our observations of direction and speed of current were used to determine the duration and frequency of flow reversals. Only those flow reversals of 60-min duration or longer were considered to constitute true reversals. Duration of flow reversal was defined as the time interval between positive downstream flows wherein the

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

downstream flow stops, then moves upstream and stops, and then moves downstream again.

Data Analysis

River discharge and height of tide are independent variables in the analysis of flow reversal in the lower Columbia River. The average monthly flow at Prescott is characterized by high bimodal peaks that occur annually in the winter and spring. The higher high tides typically occur during the same period.

River Flow

The flow of the Columbia fluctuated greatly during our study. It averaged 6,768 cubic meters per second (m^3sec^{-1}) or 239,000 cubic feet per second (cfs) and ranged from 2,209 to 14,442 m^3sec^{-1} (78,000 to 510,000 cfs). High flow occurred during June 1968 and May 1969; these high discharges were associated with water from melting snow in areas east of the Cascade Mountains. High river flow in January (Figure 1) was associated with precipitation in areas west of the Cascades. Low flows occurred during September in both years. Average monthly flows exceeded 8,495 m^3sec^{-1} (300,000 cfs) for only 5 months of the 24-month period; this fact is important in that it was only when the flow was below this level that reversal became significant at Prescott.

Tidal Height

High tides ranged from 1.5 to 3.1 m (4.9 to 10.1 ft). Tides of 2.0 to 2.6 m (6.6 to 8.5 ft) occurred most frequently. Tidal influence produces differences in water elevations in the Columbia River that can be measured upstream as far as Bonneville Dam (river km 225.3, river mile 140).

Characteristics of Flow Reversal

During the 2 years of the study, 646 flow reversals of 60 min or longer (Table 1) were observed and related to high tides. Reversals occurred most frequently in August, September, and October—normally the period of lowest discharge—and least frequently in May and June—the period of highest river discharge. Tidal heights at Astoria which produced flow reversals ranged from 1.5 to 3.0 m (4.9 to 9.9 ft).

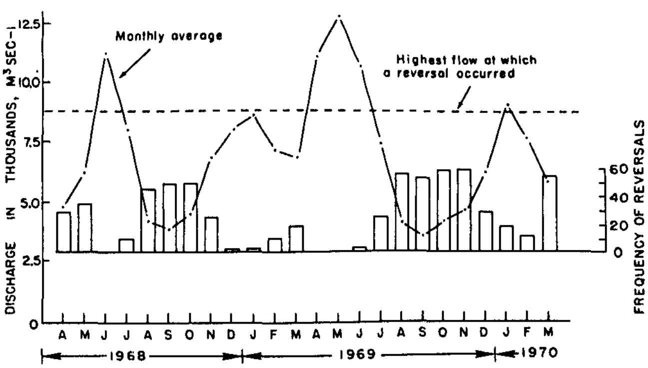

FIGURE 1.—Average monthly Columbia River discharge, at Prescott, Oreg., April 1968-March 1970. Frequency of flow reversals lasting more than 60 min and highest discharge at which a reversal occurred are also indicated.

TABLE 1.—Frequency of flow reversals (⩾ 60 min) measured in the lower Columbia River at Prescott, Oreg., April 1968-March 1970.

Period	Number of flow reversals (by month)												Total
	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
1968-69	29	35	0	10	46	49	50	26	3	3	10	19	280
1969-70	0	0	2	25	56	54	57	58	29	19	12	54	366
Total	29	35	2	35	102	103	107	84	32	22	22	73	646

Twenty-one flow reversals of 5 hr or longer were recorded. Few reversals of 60 min or longer were recorded during river discharge above 8,495 m^3sec^{-1} (300,000 cfs), regardless of the height of the tide. This relation is illustrated in Figure 1, where average monthly discharge is compared to the frequency of flow reversal.

The lowest high tide at which reversal was recorded (90 min) was 1.5 m (4.9 ft), at 3,936 m^3sec^{-1} (139,000 cfs). The highest high tide at which a reversal was recorded (155 min) was 3.0 m (9.9 ft) at 6,173 m^3sec^{-1} (218,000 cfs). Two 3-m (10-ft) tides occurred during the study period at 7,759 and 7,985 m^3sec^{-1} (274,000 and 282,000 cfs) without producing a reversal of 60 min or longer. The longest period of reversal was 5¾ hr at a tide height of 2.7 m (8.9 ft) and 5,550 m^3sec^{-1} (196,000 cfs) which occurred 8 March 1970.

A regression analysis was made for each tide level to estimate the critical discharge below which a flow reversal of 60 min or greater could be expected. Discharges that allowed flow reversals at 1.5-, 1.8-, 2.1-, 2.4-, and 2.7-m (5-, 6-, 7-, 8-, and 9-ft) tides were 4,530; 5,720; 5,861; 6,852; and 8,636 m^3sec^{-1} (160,000; 202,000; 207,000; 242,000; and 305,000 cfs; Figure 2). The rate of discharge from the river and tidal height appear to be independent variables while flow reversal is the dependent variable in the analysis.

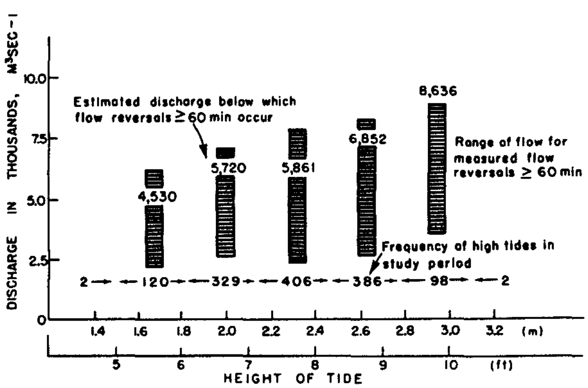

FIGURE 2.—Graphs showing range of flow of the Columbia River for various tidal heights at Astoria, Oreg. The number within each bar is the estimated discharge below which flow reversals of 60 min or longer occur at Prescott, Oreg., for a given tidal height. The number below each bar gives the frequency of occurrence of the tide height for the study period.

Discussion

During the time interval examined, reversal of direction of current (≥ 60 min) at Prescott occurred every month except June 1968 and April and May 1969. It is important to discover that the reversals in flow are frequent as previous work in this area only indicated that they could occur at very low river discharges. Because of the frequent occurrence of flow reversals in the region of the lower Columbia River near Prescott, the regulation of waste discharges in this area should receive special attention as these reversals in flow tend to produce pockets of high concentration of wastes in the river system when the waste discharges are constant in time (Clark and Snyder, 1969).

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